

A Cavity Filter Using Stepped Impedance Coupling Resonator

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Abstract — This paper presents a cavity filter based on an alternative control method using stepped impedance coupling resonators, while conventional cavity filters use coupling screws, to adjust coupling value between adjacent resonators. Using 3-D EM simulation, it is proved that coupling screws can be successfully replaced using the proposed stepped impedance coupling resonator between adjacent cavity resonators. For the proposed stepped impedance resonator, a coupling coefficient is found from a simulation in order to design a band pass filter. A proper iris area and a resonator angle are obtained using a 3-D EM simulation. The band pass filter based on the proposed stepped impedance resonator was successfully synthesized to have good pass-band and stop-band performances from the 3-D EM full-wave simulation, which verifies the proposed scheme.

Keywords— coaxial cavity filter, stepped impedance resonator, coupling, coupling coefficient

I. INTRODUCTION

Coaxial cavity filters have been widely used in mobile communication systems. Especially, the 3G mobile communication systems also employ cavity filters because the required specifications, including reliability, are very strong. So far, only the cavity filters for the RF front-ends of those wireless communication systems can satisfy all of the required specifications. The cavity filter has high selectivity, low loss, high rejection, wide stop-band, and high power transmitting capabilities. To improve these performances, many studies have been carried out [1]-[7].

Despite of many progresses for these filters, resonators with coupling screws have been popularly used [8]-[17]. Figure 1 shows a three-dimensional representation of a conventional coupling method based on a resonator which has a coupling screw and an iris in the middle of the two adjacent resonators. The total coupling between two resonators consists of both magnetic coupling and electric coupling which can be controlled by a tuning screw.

If the coupling screw gets deeper, the electric coupling gets smaller. It means that the screw decreases the electric coupling between the two adjacent resonators, which results in an increase of the total coupling.

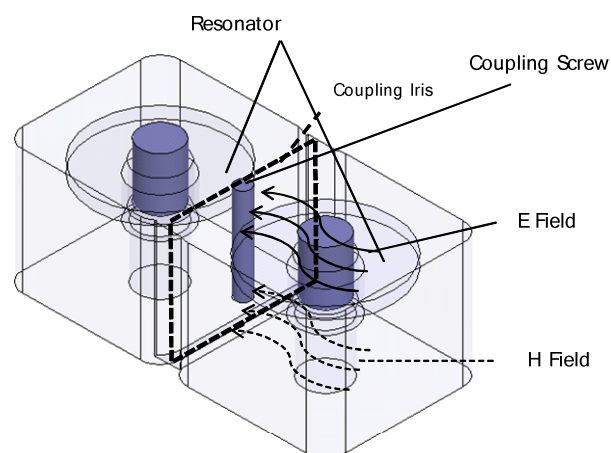


Figure 1. Conventional coupling method for the cavity filters including an iris and a coupling screw.

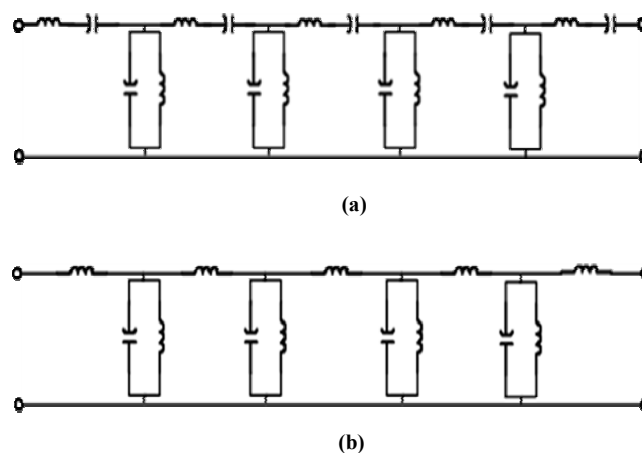


Figure 2. (a) An equivalent circuit of the cavity filter including electric field coupling, and (b) a simplified equivalent circuit excluding electric field coupling.

Likewise, the area for the iris is proportional to the coupling quantity. Increasing the area of iris increases the magnetic coupling, which increases the total coupling as well. Based on this simple coupling control scheme, we can easily achieve a proper quantity of coupling between resonators. Detailed analyses about coupling have been already dealt in many previous publications [18]-[20].

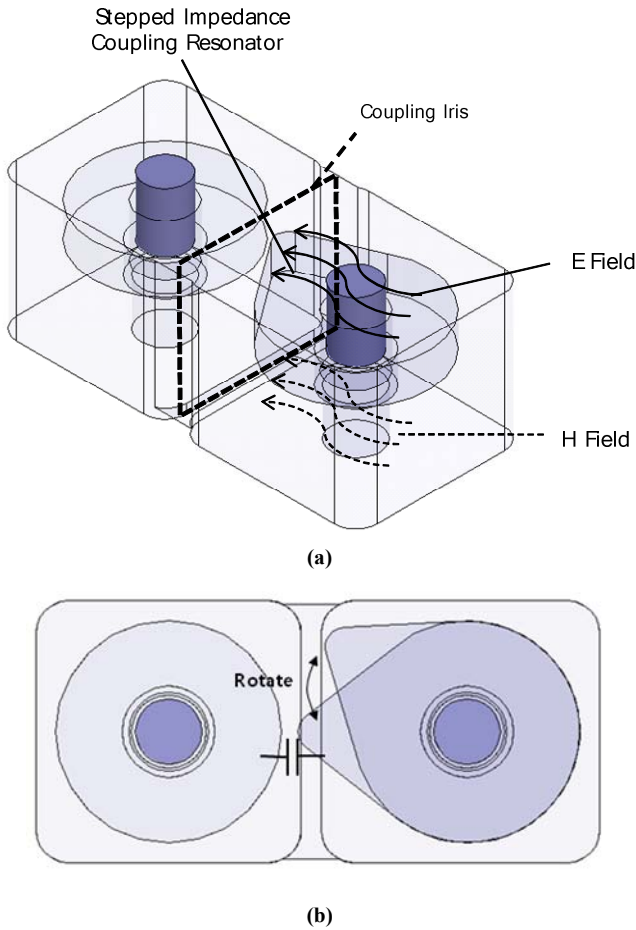
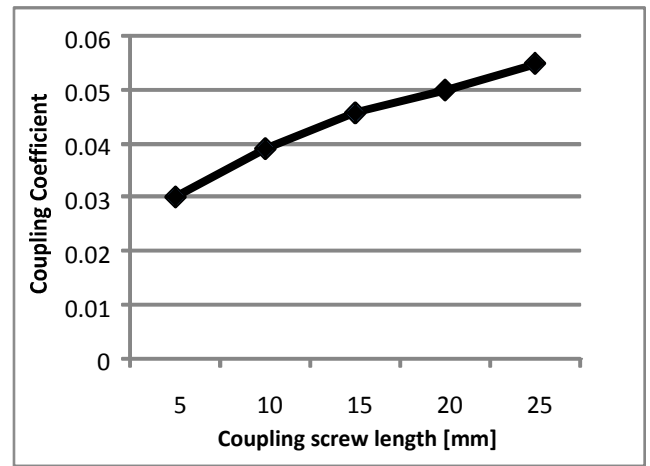


Figure 3. The proposed stepped impedance resonator: (a) a 3-D view, and (b) a top view.

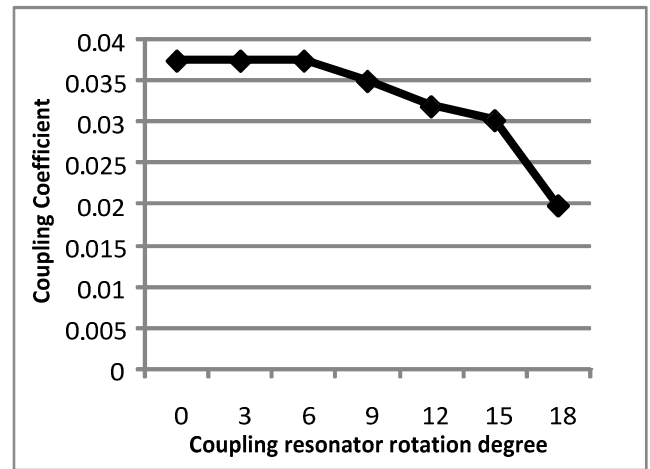
For cavity filters, a dominant coupling factor is a magnetic coupling so that we can simplify the equivalent circuit of the cavity filter from Figure 2(a) including electric coupling to Figure 2(b) excluding electric coupling.

II. STEPPED IMPEDANCE COUPLING RESONATOR

For the conventional coupling methods, both the electric coupling and magnetic coupling can be adjusted using the coupling screw and the iris area, respectively. Compared to the conventional methods, the proposed coupling method adopts a modified stepped impedance coupling resonator technique. Figure 3 shows 3-D side and top views for the proposed stepped impedance coupling resonator including a coupling iris. Instead of rotating a coupling screw, the electric coupling can be tuned by rotating the coupling resonator itself. When the degree of rotation is '0', i.e. coupling resonator indicates a center of the iris, electric coupling has its highest value. As the degree of rotation is increased, then electric coupling is decreased. As a result, the total coupling quantity can be tuned.



(a)



(b)

Figure 4. (a) Coupling coefficient vs. coupling screw length for the conventional resonator, and (b) coupling coefficient vs. a rotation angle of the stepped impedance coupling resonator.

A 3-D EM simulation tool, Ansoft's HFSS, was used to search the resonant frequencies of each resonator. The coupling coefficient is, then, a function of the resonant frequencies as:

$$k = \frac{f_2^2 - f_1^2}{f_2^2 + f_1^2} \quad (1)$$

where f_1 and f_2 are the frequencies of the two resonant poles for the two adjacent resonators. They are easily obtained through the eigenmode 3-D EM simulation.

Figure 4(a) shows coupling coefficients through various lengths of the coupling screw for the conventional resonator. Figure 4(b) shows coupling coefficients of the stepped impedance coupling resonator through various rotation angles. As the rotation angle gets narrower, the coupling increases as what we expected. Comparing both cases each other, it is found that they have similar tuning range for the coupling coefficients.

so that we can design a filter using the proposed stepped impedance resonator.

III. BAND PASS FILTER USING THE STEPPED IMPEDANCE COUPLING RESONATOR

To verify the proposed stepped impedance resonator, we designed a cavity band pass filter using a 3-D EM full wave simulation.

Table 1. BAND PASS FILTER DESIGN SPECIFICATIONS

Description	Specification
f_c	910MHz
Band width	20MHz
Chebyshev ripple	0.01dB
Attenuation	25dB @ $f_c \pm 30$ MHz

Following steps are applied to design the band-pass filter based on the 3-D EM simulation as:

- 1) Design an equivalent circuit for the resonator which has a resonant frequency of 910MHz.
- 2) Design a 4-pole band pass filter, whose schematic diagram is shown in Figure 5, using a circuit simulator of Agilent ADS. Extracted values of the series and shunt components from the circuit simulation are in table 2 as follows:

Table 2. ELEMENTS OF THE BAND PASS FILTER CIRCUIT

Element	Value
L_{01}	49.64 nH
L_{12}	413.54 nH
L_{23}	591.22 nH
L_{34}	430.38 nH
L_{45}	52.38 nH
$L_{r1} = L_{r4}$	14.21 nH
$L_{r2} = L_{r3}$	11.57 nH
Cr	2.75 pF

- 3) Simulate three different types of the resonators which are main resonator and two resonators including input and output ports shown in Figure 6. They should have a resonant frequency of 910MHz. To obtain a proper resonant frequency of the resonator, the length of

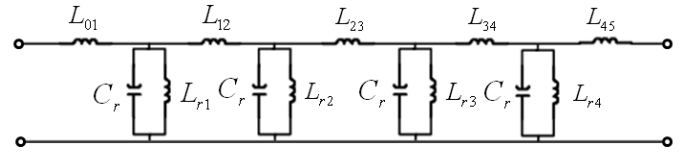


Figure 5. Equivalent circuit of the 4-pole cavity filter.

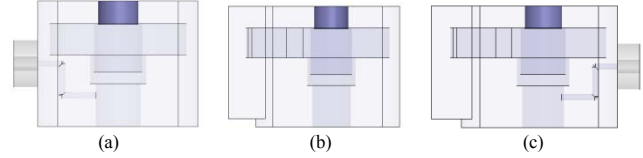


Figure 6. Three types of the cavity and resonator for the cavity filter: (a) an input resonator including an input port, (b) a main resonator, and (c) an output resonator including an output port.

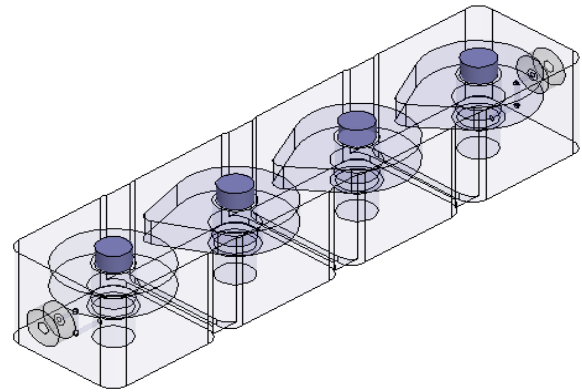


Figure 7. Structure of the band pass filter using the stepped impedance coupling resonator for the 3-D EM simulation.

the resonator and a fine tuning screw can be tuned for the simulation.

- 4) Calculate the coupling coefficient. There is simple formula for the coupling coefficient between two adjacent resonators of i and $i+1$. It is related to the pass band frequency (f_1 and f_2) and prototype elements (g_i, g_{i+1}) as:

$$k_{i,i+1} = \frac{1}{w'_1 \sqrt{g_i g_{i+1}}} \left(\frac{f_2 - f_1}{f_c} \right) \quad (2)$$

where $k_{i,i+1}$ is a coupling coefficient of the adjacent resonators. w'_1 means a pass band edge of the prototype filter. The obtained coupling coefficients are as follows:

$$\begin{aligned} k_{12} &= k_{34} = 0.0314 \\ k_{23} &= 0.0219 \end{aligned} \quad (3)$$

- 5) Find iris areas and angles of the resonators using a 3-D EM simulation. The desired iris area and resonator angles are presented in table 3.

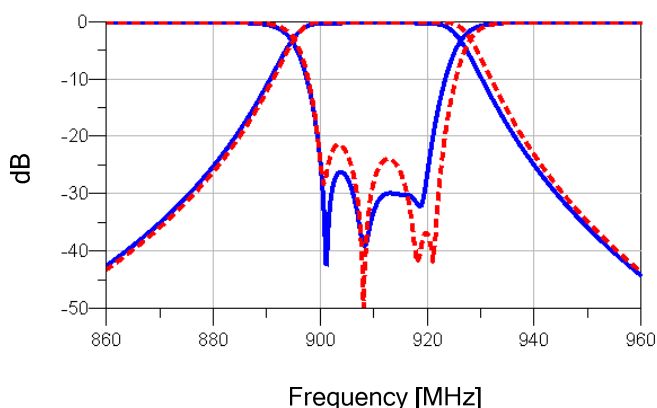


Figure 8. A circuit simulation result (solid line) vs. 3-D EM simulation result (dotted line) for the designed cavity band pass filter.

Table 3. IRIS AREAS AND ANGLES OF THE RESONATORS

Element description	Values
Iris area	32.2mm x 39.0mm
Angle of Res.1	9.5 degree
Angle of Res.2	9.0 degree
Angle of Res.3	16.5 degree

Figure 7 shows a structure of the band pass filter using the stepped impedance coupling resonator for 3-D EM simulation. As planned, all coupling screws are removed except fine tuning screws above the resonators for fine tuning. The fine tuning screws compensates for a possible resonant frequency shift for the first and fourth resonators which have input and output port connectors, respectively. Figure 8 shows the simulated frequency responses of the cavity band pass filter. As shown, the circuit simulation results and the 3-D EM simulation results match very well.

IV. CONCLUSION

A novel stepped impedance resonator is proposed for a cavity resonator filter design. Different from the conventional resonators, it requires no tuning screws. To verify the new coupling method, the simulated coupling coefficients were compared to the conventional resonator using tuning screws. The 3-D EM full wave simulation was conducted to design a cavity band pass filter. The results satisfy the expected coupling range and specifications of the band pass filter. Consequently, the proposed stepped impedance coupling resonator can provide easier and simpler way to couple adjacent resonators.

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